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(54) **Pump noise filtering apparatus for a borehole measurement while drilling system utilizing drilling fluid pressure sensing.**

(57) An apparatus for removing pulsation noise caused by a well drilling fluid circulating pump from fluid pressure pulse transmitted measurement while drilling data passing through drilling fluid in a drill string of a borehole measurement while drilling system. The noise filtering apparatus includes a drilling fluid pressure sensor and an adaptive estimator that memorizes the pulse noise signature of a pump in synchronization with the pump's strokes. The memorized signature is removed from the signal data derived from pressure pulsations in the drilling fluid in order to remove or filter the pump's noise or pressure signal disturbing influence from this data. The adaptive estimator is arranged such that it will compensate for changing operating conditions of the pump so that this pump created noise is substantially, continuously filtered from the measurement while drilling data.

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PUMP NOISE FILTERING APPARATUS FOR A BOREHOLE MEASUREMENT WHILE DRILLING SYSTEM UTILIZING DRILLING FLUID PRESSURE SENSING

Technical Field

This invention is related to data transmission systems for borehole telemetry or measurement while drilling systems. More specifically the invention is related to a measurement while drilling system wherein data is transmitted from the downhole instrument through pressure pulsations of the drilling fluid within the drill string to the earth's surface. The invention is directed to an apparatus for filtering data passed through pressure pulsations in the drilling fluid from downhole equipment to the earth's surface in order to remove the influence of data disturbing pressure pulsations occurring because of the drilling fluid circulating pump.

Background of the Invention

In the petroleum and related borehole drilling industries there has long been a need for a telemetry or measurement while drilling system to obtain real time data from the bottom of the borehole as it is being drilled. The parametric conditions of the environment in the vicinity of the drill bit can provide significantly valuable information to assist in the drilling of the borehole. Particularly, this information is of great assistance to make the best use of equipment and manpower needed for drilling a borehole. There are four basic types of systems developing for the communication and to transmission of this data from the bottom of the borehole to the earth's surface. These

systems include transmission of the data by electromagnetic methods, insulated conductor or hardwire systems, acoustical methods and pressure pulse modulation of the drilling fluid or mud. Each of these systems has its advantages and disadvantages and the particular system with which this patent application is concerned utilizes the mud pressure pulse concept.

In a measurement while drilling system utilizing mud pressure pulsation as a technique to transfer data, it is subject to interference caused by other pressure pulsations in the drilling fluid flow path. The primary source of these interferring pressure pulsations is the circulating pump(s) for the drilling fluid or mud. This circulating pump contains a plurality of pistons, valves and other mechanical hardware that not only move the drilling fluid through the drill string but create pressure pulsations which represent noise or interference with respect to the pressure pulsations produced by the transmitter of the measurement while drilling equipment. Because the measurement while drilling system uses the drilling fluid as a pathway for transmission of data noise or pressure interference is undesirable. The noise or interference in pressure pulses produced by the drilling fluid circulating pump can be of such a magnitude that it will substantially mask or obscure the data from the measurement while drilling equipment unless it is properly removed by the data receiving equipment at the earth's surface. In studying this noise or interference it has been noted that the character of the interference produced by a particular drilling fluid circulating pump is not uniform and will vary between types of pumps, manufactures of pumps, and even between identical pumps at a installation. Also, the characteristic pressure pulsations for a specific pump will change in relation to the operating speed of the pump. In view of this it is observed that if a noise or interference filter is to be effective in filtering or removing this pulse pressure interference it must be able to

accommodate the changing conditions between installations and particular equipment to be feasible for commercial operation and to be practical equipment to be feasible for commercial operation and to be practical to accommodate changing conditions as they might occur on a particular drilling rig. Accordingly, it is a purpose of this invention to solve the above described problem and provide a filtering system to remove this objectionable noise or interference from the drilling fluid or mud flow stream.

Summary of the Invention

In an embodiment, a pump noise filtering apparatus for a borehole measurement while drilling system includes an adaptive estimator having a memory that utilizes samples of pressure and velocity measurements taken from the drilling fluid flow stream in a sequence related to cyclic operation of the mud pump. Signals related to these pressure measurements are stored and then removed from the continuing pressure signal measurements in a sequence correlated to the pumps cyclic operation in order to remove this noise or interference from the sensed data prior to passing it into a receiver, processor and display portion of the measurement while drilling system. The stored signal data is refreshed with each pump cycle in order to adjust the data for changing pump noise conditions.

One object of this invention is to provide a pump noise cancelling apparatus overcoming the aforementioned difficulty in the art.

Still, one other object of this invention is to provide a pump noise cancelling or filtering apparatus for a measurement while drilling system that has an adaptive estimator that will selectively recognize the character and magnitude of the pressure pulse influences from a drilling fluid circulating pump or mud pump of a drilling rig and including other circuitry that will selectively remove this influence from the pressure modulated data from the measurement while drilling system that is extracted from the drilling fluid flow stream in the transmission of this data to the earth's surface.

Still, another object of this invention is to provide a pump noise cancelling apparatus that will adapt to changing pump noise or interference conditions in order to provide substantially continuous reception of data that is transmitted from a downhole measurement while drilling sensing instrument to associated receiving and processing equipment at the earth's surface without regard to the modulation technique used to transmit the data.

Various other objects, advantages and features of this invention will become apparent to those skilled in the art from the following discussion, taken in conjunction with the accompanying drawings in which:

Description of the Drawings

Fig. 1 is a schematic and pictorial representation of a measurement while drilling apparatus using a pressure modulation transmission technique and installed in an earth borehole;

Fig. 2 is a schematic diagram of the receiving and noise filtering apparatus circuit for the present invention where a single mud pump is utilized;

Fig. 3 is a more detailed schematic diagram of the noise filtering apparatus filter circuit of this invention;

Fig. 4 is a detailed schematic of an adaptive estimator circuit that can be used in this invention; and

Fig. 5 is a schematic diagram of the noise filtering apparatus circuit for use in the present invention where a plurality of mud pumps are present.

The following is a discussion and description of preferred specific embodiments of the pump noise filtering apparatus of this invention, such being made with reference to the drawirgs, whereupon the same reference numerals are used to indicate the same or similar parts and/or structure. It is to be understood that such discussion and description is not to unduly limit the scope of the invention.

Detailed Description of the Preferred Embodiment

This invention may be embodied in a borehole measurement while drilling system as illustrated

in Fig. 1. As shown the borehole measurement while drilling system is used with conventional well drilling equipment wherein a drill string 10 comprised of segments of drilling pipe having a drilling bit 12 at the bottom end thereof are used to drill a borehole 14 through an earth formation 16. The measurement while drilling apparatus includes at least one sensor 18 in the lower portion of drill string 10 to sense a physical parameter of the geophysical borehole environment. Sensor 18 can for example be an orientation device to sense the direction and inclination of the adjoining portion of borehole, or it can be one or more other devices that are operable to measure borehole temperature, pressure, weight applied to the bit, or a variety of other parameters that may be desired.

Information or data from sensor 18 is communicated to a transmitter 20 in the drill string 10. This data is then passed by transmitter 20 to the earth's surface. Transmitter 20 in this type of measurement while drilling system is a device known in the art to encode data from sensor 18 into pressure pulsations in the drilling fluid or mud that is contained within drill string 10. These pressure pulsations travel through the drilling fluid or mud upward from their point of origin at transmitter 20 to the surface equipment where the pressure pulsations are sensed by a pressure sensor 22. Pressure sensor 22 is communicably connected with the interior of a conduit 24 through which the drilling fluid or mud passes. This conduit 24 is in a portion of the drilling flow loop between the drilling fluid mud pump 26 and a swivel connection 27 at the upper end of drill string 10. Pressure sensor 22 is electrically connected with a receiver 28 that is used to extract the intelligence carrying data from the pressure measurements taken at drilling fluid flow line conduit 24. The pump noise filtering or cancelling apparatus of this invention would normally be contained within receiver 28 of this measurement while drilling system. From receiver 28 the data is transmitted to a data processor and display

apparatus 30 that is operable for mathematically manipulating, further processing, and displaying the data in a desired and usable form such as a visual representation, a magnetic tape or a printed document.

Drilling fluid circulating pump 26 is the primary source of the noise or interference that is sought to be removed by the apparatus of this invention. For the typical oilfield operation this pump is a reciprocating piston type pump in either a duplex (two piston) or triplex (three piston) construction. A great many of these pumps are single acting pumps however some of them may be double acting pumps. In either case they have the fluid flow into and out of them controlled by check valves. The normal operation of these pumps will provide a substantially high pressure source of drilling fluid at a significant flow rate for the normal drilling operation as is well known in the industry. Because of the reciprocating nature of these pumps and their use of check valves, they produce pressure pulsations in the drilling fluid flow stream. The nature and characteristics of these pressure pulsations depends upon the particular physical construction of the specific pump. It has been observed that these pressure pulsations or fluctuations in the drilling fluid are cyclical in relation to the strokes of the pump and that this produces a cyclic or periodic pressure pulsation pattern in the drilling fluid as detected by pressure sensor 22 in drilling fluid flow line conduit 24. Drilling fluid pump 26 is fitted with a pump stroke sensor to permit the monitoring of the pump's strokes at a preselected point within its pumping cycle. This pump stroke sensor includes a pickup device 29 that is mechanically mounted at the pump and adapted to sense the pump's position at a regular occurring interval of the pump stroke cycle in order to provide data for correlating the pressure pulse cycle of the drilling fluid. The output of pump stroke sensor pickup 29 is connected to receiver 28.

Fig. 2 shows a schematic representation of the pump noise filtering apparatus circuitry of this invention

in a block diagram form. The wave forms shown at various portions of Fig. 2 indicate the shape of the various signals at the several portions of the apparatus. Pump 26 has its pump stroke sensor connected to a timing circuit 32. The output signal from the pump stroke sensor is a plurality of pulses spaced apart in a sequence corresponding with strokes of the pump so that timing circuit 32 can use this pump stroke signal to generate a signal that is responsive to the repetitive strokes of drilling fluid circulating pump 26. The output from timing circuit 32 is chosen to be a square wave as illustrated. Pressure sensor 22 provides continuous pressure sensing of pressure pulsations or fluctuations in drilling fluid flow line conduit 24. When the measurement while drilling system is operating the output signal from pressure sensor 22 contains the combined pressure pulsations of the measurement while drilling transmitter and the pressure pulsations emanating from drilling fluid circulating pump 26 because both of these are present in the drilling fluid flow line conduit 24. The wave form shown in Fig. 2 is representative of the output signal from pressure sensor 22. This signal contains some peaks that are significantly higher than others. The larger peaks are representative of positive pressure pulses from pump 26. Other peaks in this wave form can possibly be suspected as coming from the measurement while drilling transmitter. However specific correlation and identification of this data by only a visual examination is ineffective and inaccurate. The signal from pressure sensor 22 is directed into an adaptive estimator circuit 34 and also into a subtraction circuit 36. The output from adaptive estimator circuit 34 is also directed into subtraction circuit 36.

Adaptive estimator circuit is connected to receive the output from timing circuit 32, to receive an output from pressure sensor 22, and provide an output that is fed into subtraction circuit 36. Adaptive estimator circuit 34 is provided with circuitry to memorize or store data that is representative of specific portions of the pressure sensor output signal in correspondence with strokes of the pump and

in correlation with the output signal from timing circuit 32. The output from the pressure sensor is divided into a plurality pressure sample segments between like portions of each pump stroke interval. During each pressure data sample segment the pressure sensor data is sampled by and stored in adaptive estimator circuit 34. Thus for each stroke of the pump (one pump stroke interval) a plurality of samples of the drilling fluid pressure sensor data are taken (one in each pressure sample segment). As these samples of the drilling fluid pressure data are accumulated the stored or representative value in adaptive estimator circuit can be changed with each repetitive stroke of the pump. This is done in order to permit the data stored in the adaptive estimator circuit to closely follow the pumps operation and thus accommodate changing operating conditions. This adaptive estimator circuit 34 performs the function of a tracking commutative filter which is to estimate the approximate value of the following data sample in each pressure sample segment by retaining the sum of previous such weighted values and modifying or adjusting that value to correspond with a new data sample during that particular pressure sample segment of each pump stroke interval.

This adaptive estimator circuit 34 includes a memory that functions to retain a representative of the data from the pressure sensor. This memory must be capable of adapting or varying its retained data to accommodate changing data that is resultant from the operating conditions at a well. In general the adaptive estimator circuit 34 functions as a specific adaptation of a filter generally known as a tracking commutative filter. An example of such a changing condition is a simple change in the pump's operating speed that would affect the pulse rate from the pump stroke sensor. An additional change that might influence the pump's pressure pulse characteristics would be raising the drill string from the drilling position so that drill bit 12 instead of being at the bottom of the borehole is in an elevated position a short distance above the borehole bottom. This is a condition that might be used

for temporary circulation of the drilling fluid.

The memory of adaptive estimator circuit 34 can be an analog type memory circuit or it can be a digital type memory circuit depending upon the desire of the designer. Regardless of which type of memory circuit is used the operable parameters are the same because of the needed function this portion of the apparatus. For illustration of a specific memory configuration Figs. 3 and 5 depict an analog memory circuit that can be used with the apparatus and method of this invention. The circuit of Fig. 5 will be described in greater detail following the description of Figs. 1-3.

Returning to the description of Figs. 1 and 2 subtraction circuit 36 is provided with an input from pressure sensor 22 and an input from adaptive estimator circuit 34. Subtraction circuit 36 functions to remove from the pressure sensor signal those portions which are indicative of the pressure pulsations that are sequenced with and related to drilling fluid circulating pump 26. This removal of the selected portions of the data signal from the pressure sensor is done in correlation with the pump strokes as by timing circuit 32. Removal of these portions of the pressure sensor signal is done by subtracting from the pressure sensor signal a value representative of those portions of the pressure sensor signal which occur in a repetitive, correlatable sequence with the pump's strokes. The resultant signal from this subtraction or removal process carries the intelligence data from the transmitter of the measurement while drilling apparatus with the distorting influence of drilling fluid circulating pump 26 having been substantially removed. A wave form generally representative of this signal is shown in Fig. 2 between subtraction circuit 36 and 38.

Comparator 38 performs a function of comparing the output signal from subtraction circuit 36 with a predetermined signal value in order to eliminate spurious or extraneous portions of the data signal prior to passing the signal to the receiver, processor and display in order to

reduce the possibility of erroneous data. Comparator 38 includes a circuit that compares the value of the data signal with a predetermined value or range of values (at the desire of the user) and from this signal the comparator provides an output signal indicative of and timewise correlatable with the data signal that is representative of those portions of the data signal that meet the criteria of being greater than or being within a predetermined range of values. A wave form representative of the output of comparator 38 is illustrated in Fig. 2. From comparator 38 the data signal shown is in a form that can be utilized by appropriate digital, encoding equipment and circuitry to remove and decode the intelligence data from the signal. Depending upon the apparatus used the output from comparator 38 can pass into a decoding portion of the receiver or processor for further data manipulation, handling, etc.

Fig. 3 shows in block diagram schematic form an embodiment of the adaptive estimator circuit and the subtraction circuit portions of this invention. Pump stroke sensor 40 associated with drilling fluid circulating pump 26 provides a pulsed output signal as shown. This output signal is fed into a flip flop circuit 42 that shapes the signal into a rectangular wave form as illustrated. Phase lock loop circuit 44 receives the output from flip flop circuit 42 and functions to synchronize its output timing pulses with the timing pulse signal from pump stroke sensor 40 so that each timing pulse from flip flop circuit 42 occupies a fixed and constant time interval with respect to the pump stroke cycle. The output from phase lock loop circuit 44 is connected to an input of adaptive estimator circuit 34.

Pressure sensor 22 has its output signal connected to the input of a buffer amplifier 46 that functions to condition the magnitude of this signal for use by the adaptive estimator circuit and in other portions of the circuit. A generally representative wave form of this data signal is illustrated in Fig. 3 between pressure sensor 22 and buffer 46.

It is to be noted that this wave form is only generally representative of the wave form that can occur at this location. The specific shape of the typical or representative wave form will vary depending upon the speed of operation of the drilling fluid circulating pump and also upon the static pressure in the drilling fluid conduit 24. Because this wave form is subject to some changes in shape it will influence the wave form output from adder circuit 50. The illustrated wave forms shown in Figs. 2 and 3 are to be considered as approximate or representative or illustrative of the actual wave forms that may be present in actual practice of this invention.

Adaptive estimator 34 is described above and functions to prewhiten or process before manipulation the data signal received from buffer 46 during the pressure sample time segments designated by the timing circuit. It receives signals from phase lock loop 44 and from buffer 46 and provides a data signal to the input of an inverter 48.

The subtraction portion of this circuit is accomplished in this embodiment by an inverting amplifier 48 ccupled with an adding amplifier circuit or adder 50. Inverting amplifier 48 inverts or changes the sign of the data signal from adaptive memory 34 so that when it is added to the data signal from buffer 46 the result will be an additive removal or subtraction of the representations of the selected pressure pulse characteristics stored in the memory of adaptive estimator 34 from the pressure data signal output of buffer 46. The resultant data signal output from adder 50 can be in a wave form that has a plurality of well defined peaks as illustrated in Fig. 3. This resultant data signal is then supplied to comparator 38 for selection of the output data signal by comparing the received data signal with predetermined reference values as described previously.

An example of an analog type of adaptive estimator is shown in Fig. 4. The circuit shown in Fig. 4 includes an analog type of memory and other analog devices to interface with other connecting portions of the circuitry in this

apparatus. Similar elements in Figs. 3 and 4 have the same numerals. The pressure pulse related data signal from pressure sensor 22 is supplied to the input of buffer 46. The output of buffer 46 is divided with one portion going to the input of inverter 48 and the other portion going to the input of the adaptive memory or tracking commutative filter. The adaptive memory or tracking commutative filter has a plurality of capacitors 52 connected in parallel between a buss line 55 carrying the output from buffer 46 and a multiplexing circuit 54. Multiplexing circuit 54 basically functions as a plurality of switches that function to connect the plurality of capacitors 52 one at a time between ground and buss line 55 in sequence with timing signals from phase lock loop circuit 44. Multiplexing circuit 54 can be a conventional integrated circuit having a plurality of multiplexing parts corresponding with the number of pressure sample segments that are selected for divisions of the pump stroke interval. The clock or timing sequence input to multiplexer 54 is through a plurality of connections from phase lock loop circuit 44. For each pump stroke interval the plurality of capacitors are each sequentially connected during their associated portion of the pump stroke interval or during their designated pressure sample segment of that interval. The capacitors are each charged to a value approximating the value of the data signal during the interval in which they are individually connected. Charging the capacitors in this manner provides a long term average of the data signal value during the pressure sample segment time interval as is well known in commutative filters.

The output from this adaptive memory is via the buss line 55 to a gain amplifier 56. The output of gain amplifier 56 and the output of inverter 48 are combined at adder 50 (enclosed in dashed lines) with the composite resulting signal being additionally increased by another gain amplifier 58. The output of amplifier 58 is connected to the input of comparator 38 or comparison of the processed data signal with a predetermined value or range of values as described in the preceding.

In the situations where a plurality of drilling fluid circulating pumps are used in a drilling rig having a measurement while drilling apparatus it is necessary to provide a plurality of cascaded pump noise cancelling devices in order to selectively remove the noise or pressure pulsation influence of these specific pumps.

Fig. 5 illustrates in schematic block diagram form such a pump noise filtering apparatus which is representative of that which could be utilized filter the pump noise or interference in the pressure pulse data for a drilling rig having two or more drilling fluid circulating pumps. The circuit shown in Fig. 5 includes a single pressure sensor 60 adapted to sense the pressure on a drilling rig in the drilling fluid flow conduit at a point between the location where fluid flow from the plurality of mud pump flow conduits merge and the location where this combined flow passes into the drill string. This circuit is shown with a pair of drilling fluid circulating pumps identified as a first pump 62 and a second pump 64. In this circuit the effect of the first pump 62 is first removed from the data signal then the effect of the second pump 64 is removed from the data signal. The first pump 62 is provided with a pump stroke counter circuit that provides pump stroke timing signals to first timing circuit 66. Data from first timing circuit 66 and a drilling fluid pressure sensor 60 are supplied to a first adaptive memory 68. The output signal from drilling fluid pressure sensor 60 is a second signal data input to first adaptive estimator circuit 68. The output from first adaptive estimator 68 is supplied to a first subtraction circuit 70 along with the signal or data from pressure sensor 60. The output from first subtraction circuit 70 is essentially the data of pressure sensor 60 with the effect of the first pump 62 removed therefrom. This data provides the input to the portion of the circuit for eliminating or filtering the effect of the second pump 64.

Second pump 64 is provided with a pump stroke counter circuit the output of which provides sequential pump

stroke data to the input of second timing circuit 72. The output from second timing circuit 72 is to one input of second adaptive estimator 74 along with an input from first subtraction circuit 70. The output of second adaptive estimator 74 is coupled to one input of second subtraction circuit 76. An output from first subtraction circuit 70 is provided to second subtraction circuit 76. The output from second subtraction circuit 76 has the effect of pressure pulse interference from both pumps 62 and 64 removed or filtered from the pressure signal data and this data is supplied to comparator 78 for comparison with a preselected range of values as described above. The output from comparator 78 is to a data receiver, processor and display essentially as described in the preceding embodiment.

In the use and operation of the pump noise filtering apparatus of this invention, it is seen that the same provides a combination of apparatus and circuitry for substantially removing the noise or interference caused by a drilling rig's well drilling fluid circulating pump into the data communication medium for a pressure pulse modulation type system of communication in a measurement while drilling system. This invention is operable with mud pressure modulated communication systems utilizing positive or negative signal pressures and continuous wave or pulse modulation. Although this invention is described with a pressure pulse modulated data transmission system it is to be understood that it is equally operable with other modulation systems. Because of the adaptive estimator this apparatus will adapt itself to the particular pump and pump noise environment of a particular drilling rig. Also since the form of memory used in the adaptive estimator can be either an analog form or a digital form depending upon the equipment choice of the user. This apparatus can be used with installations having a single pump or installations having multiple pumps. Because the adaptive estimator is sequenced with the strokes of the associated pump it is in effect tuned to memorize representations of the data signal spectrum in which the pressure data signal is contained.

Thus, when the memorized signal is removed from the entire spectrum in a selective manner coordinated with the pump strokes it is adapted to remove a representation of the noise due to the pump. Because this particular noise is the major contributor to noise or interference in this pressure medium it removes the undesirable portions of the pressure pulse data signal thereby in effect filtering the data signal so that it can be easily and accurately converted to a usable digital or analog form compatible with the measurement while drilling systems processing and recording equipment.

Although specific preferred embodiments of this invention have been described in detail in the preceding description. This description is not intended to limit the invention to the particular form or embodiments disclosed herein since they are to be recognized as illustrative rather than restrictive and it would be obvious to those skilled in the art that the invention is not so limited. For example, the described analog memory could be a digital memory provided with appropriate analog to digital conversion circuitry. Also provided that a digital memory is used the conversion from an analog signal to a digital signal could be made at the pressure sensor and at the pump sensor if desired.

Thus the invention is declared to cover all changes and modifications of the specific example of the invention herein disclosed for purposes of illustration which does not constitute departures from the spirit and scope of the invention.

The embodiments of the invention in which an exclusive property or privilege is claimed or defined as follows:

1. In a borehole measurement while driling system for passing data in the form of a modulated data signal stream through drilling fluid in a drill string, a circuit means for substantially removing interferring pressure pulsations caused by a drilling rig's driling fluid circulating pump from the data stream comprising:

(a) means for generating a first signal responsive to the repetitive strokes of a drilling fluid circulating pump;

(b) means for generating a second signal responsive to fluid pressure in a drilling fluid medium that is carrying a pulsed data stream and has pressure pulses from a drilling fluid circulating pump;

(c) an adaptive estimator means adapted to receive said first signal and said second signal and retain as a stored signal a long term average representation of said second signal in a sequence coordinated with said first signal and strokes of said pump;

(d) a subtraction means coupled to said adaptive estimator means and said means for generating a second signal and operable to receive said second signal for subtracting said stored signal from said second signal in a sequence related to the strokes of said pump such that a resultant signal is produced that is representative of the data signal of the borehole measurement while drilling system that was introduced into the drilling fluid.

2. The circuit means of claim 1 wherein:

(a) said means for generating a first signal has a pulse generator operable to produce a timing pulse signal indicative of a repetitively reoccurring event correlated to the strokes of a drilling fluid circulating pump; and

(b) said subtraction circuit has an inverting circuit connected to receive said stored signals from said adaptive estimator means and an adder circuit to combine signals from said inverting circuit with said second signals in order to arrive at said resultant signal.

3. The circuit means of claim 1, additionally including a comparator means receiving said resultant signal and operable to compare it with a predetermined value in order to selectively provide a filtered output signal indicative of said pulsed data signal.

4. The circuit means of claim 1, wherein said adaptive estimator means comprises a tracking commutative filter having an analog memory means adapted to receive portions of said second signal as an analog signal during discrete time intervals correlated with said first signal during repetitive strokes of said pump in order to retain a representation of said second signals to make them available for sampling at later time intervals.

5. The circuit means of claim 4, wherein said analog memory means has a multiplexing means connected to a plurality of capacitors and operable to permit sequential selectively charging said capacitors to values corresponding with values of said second signal occurring during said discrete time intervals.

6. The circuit means of claim 1, wherein said adaptive estimator comprises a tracking commutative filter having a digital memory means adapted to receive said first signal and said second signal and operable in a digital format toretain as said stored signal a representation of said second signal occurring during discrete time intervals correlated with said first signal in order to provide an output signal for said subtraction means.

7. The circuit means of claim 6, wherein said subtraction means has means to receive said second signal and produce a digital representation thereof and means to subtract said stored signal from said digital representation of said second signal in correspondence with said repetitive pump strokes such that said resultant signal is produced in a digital format.

8. The circuit means of claim 7, wherein said subtraction means has means to subtract said memory stored signal from said digital representation of said second signal during selected time segments in correspondence with said pump strokes in order to produce said resultant signal.

9. In a borehole measurement while drilling system for passing data signals in the form of a modulated data signal through drilling fluid in a drill string a circuit means for removing interferring noise from the data signal that is generated by a plurality of borehole drilling fluid circulating pumps, comprising:

(a) a plurality of means for generating a plurality of first signals each being responsive to the individual repetitive strokes of separate drilling fluid circulating pumps of said plurality of pumps;

(b) means for generating a second signal responsive to fluid pressure in a drilling fluid medium carrying a pulsed data signal and also interferring noise pressure pulses from said plurality of drilling fluids circulating pumps;

(c) a plurality of adaptive estimator means with each being associated with said means for generating said first signal and each being adapted to receive the associated first signal and to receive another data signal, to retain a representation of said other data signals in a sequence coordinated with strokes of the associated pump as identified by said associated first signals, and to provide a retained signal;

(d) a plurality of subtraction means, each being associated with an adaptive estimator means, coupled thereto to receive said retained signal, and each receiving said data signal such that subtraction of said retained signal may be subtracted from said data signal in a sequence related to the strokes of said associated pump such that a resultant signal is generated that has the influence of said associated pump removed therefrom; and

(e) the associated combination of an adaptive estimator means and a subtraction means are arranged in a cascading manner to one another wherein each associated said adaptive estimator means and said subtraction means are cooperatively operable with an associated pump to filter the influence of that pump from the data signal prior to providing the produced, retained signal to the subsequent associated adaptive estimator means and subtraction means, and further wherein the data signal supplied to the first of said adaptive estimators is said second signal and the signal of the last subtraction means is a composite data signal representative of the data signals that are placed in the drill string by measurement while drilling apparatuss operably connected to the drill string.

10. In a borehole measurement while drilling system for passing data signals in the form of a modulated data signal through drilling fluid in a drill string, a circuit means for removing inteferring noise from the data signal that is caused by a plurality of borehole drilling fluid circulating pumps, comprising:

(a) means for generating a plurality of first signals each being responsive to the repetitive strokes of separate drilling fluid circulating pumps;

(b) means for generating a second signal responsive to fluid pressure in a drilling fluid medium carrying a modulated data stream and including interferring noise pressure pulses from said plurality of drilling fluids circulating pumps;

(c) a first adaptive estimator means associated with one of said means for generating said first signal and being adapted to receive said associated first signal and receive said second signal and retain a representation of said second signals in a sequence coordinated with the associated said first signals and strokes of a first asscciated pump;

(d) a first subtraction means, associated with said adaptive estimator means, coupled thereto and receiving said second signal such that subtraction of said retained representation of said second signal may be subtracted from said second signal in a sequence related to the strokes of said associated pump such that a first resultant signal is produced that has the interferring noise influence of said associated pump removed substantially therefrom;

(e) another adaptive estimator means associated with another of said drilling fluid circulating pumps and its associated means for generating said first signal and being adapted to receive said associated first signal and said second signal and retain another representation of said second signal in coordination with the associated said first signals and strokes of the associated pump;

(f) another subtraction means associated with said another adaptive estimator means, coupled thereto and also receiving said second signal such that subtraction of said other retained representation of said second signal may be subtracted from said second signal in a sequence related to strokes of said other pump such that a second resultant signal is produced that has the interferring noise influence of said first associated pump and said other associated pump substantially removed therefrom; and

(g) a comparator means connected to receive said second resultant signal and compare such with predetermined characteristics in order to determine if said second resultant signal is within such characteristics and generate an output signal correlated to said second resultant signals having such characteristics.

11. In a borehole measurement while drilling system for a drilling rig with a drill fluid circulating pump, comprising:

(a) a sensor in a drill string adapted to sense a geophysical parameter in a borehole and produce a data signal representative of the sensed physical parameter;

(b) a transmitter for transmitting a representation of said data signal as a transmitted data signal through a drilling fluid in the drill string in a fluid pressure modulated data transmission format;

(c) a receiver at the earth's surface for receiving said transmitted data signal through a pressure transducer in fluid communication with drilling fluid in said drill string and producing an output representative of the data signal of said sensor and also representative of said sensed physical parameter;

(d) said receiver having a filter means therein adapted to remove from said transmitted data signal the pressure pulse influence of said drilling fluid circulating pump such that said transmitted data signals may be recovered without such interference;

(e) said filter means includes, a timing circuit means for sensing strokes of said pump and producing a timing signal representative thereof, an adaptive estimator means receiving said timing signal and a pressure data signal from said pressure transducer and operable to temporarily store the data signal from said pressure transducer in correlation with said timing signal and to produce an output signal in correlation with said timing signal that is representative of an extended term relation

to said pressure data signal, a subtraction means operable to receive said pressure data signal from said pressure transducer and selectively remove therefrom said adaptive estimator output signal in correlation with said timing signal in order to reproduce said composite data signal representative of the data signal of said sensor; and a comparator means receiving said composite data signal and having means to compare that data signal with a predetermined value and determine if said composite data signal is within predetermined value limits and produce therefrom an output data signal representative of the data signal of said sensor and related to the sensed geophysical parameter.

12. The borehole measurement while drilling system of claim 10, wherein:

(a) said timing circuit means timing signal is representative of the stroke rate of the associated drilling fluid circulating pump and a plurality of segment divisions thereof;

(b) said adaptive estimator means includes a memory means operable to store a representation of said pressure transducer data in a plurality of designated data segments corresponding with said plurality of segmented divisions of said timing signal and further operable to provide access to such stored representations of said pressure transducer data.

13. The borehole measurement while drilling system of claim 10, wherein said adaptive estimator means has a tracking commutative filter means operable to receive said timing signal and said pressure data signal from said pressure transducer and to provide a filtered output signal for said subtraction means.

14. The borehole measurement while drilling system of claim 10, wherein said transmitter for said data signal uses pulse modulation to modulate the data signal for transmission in the drilling fluid.

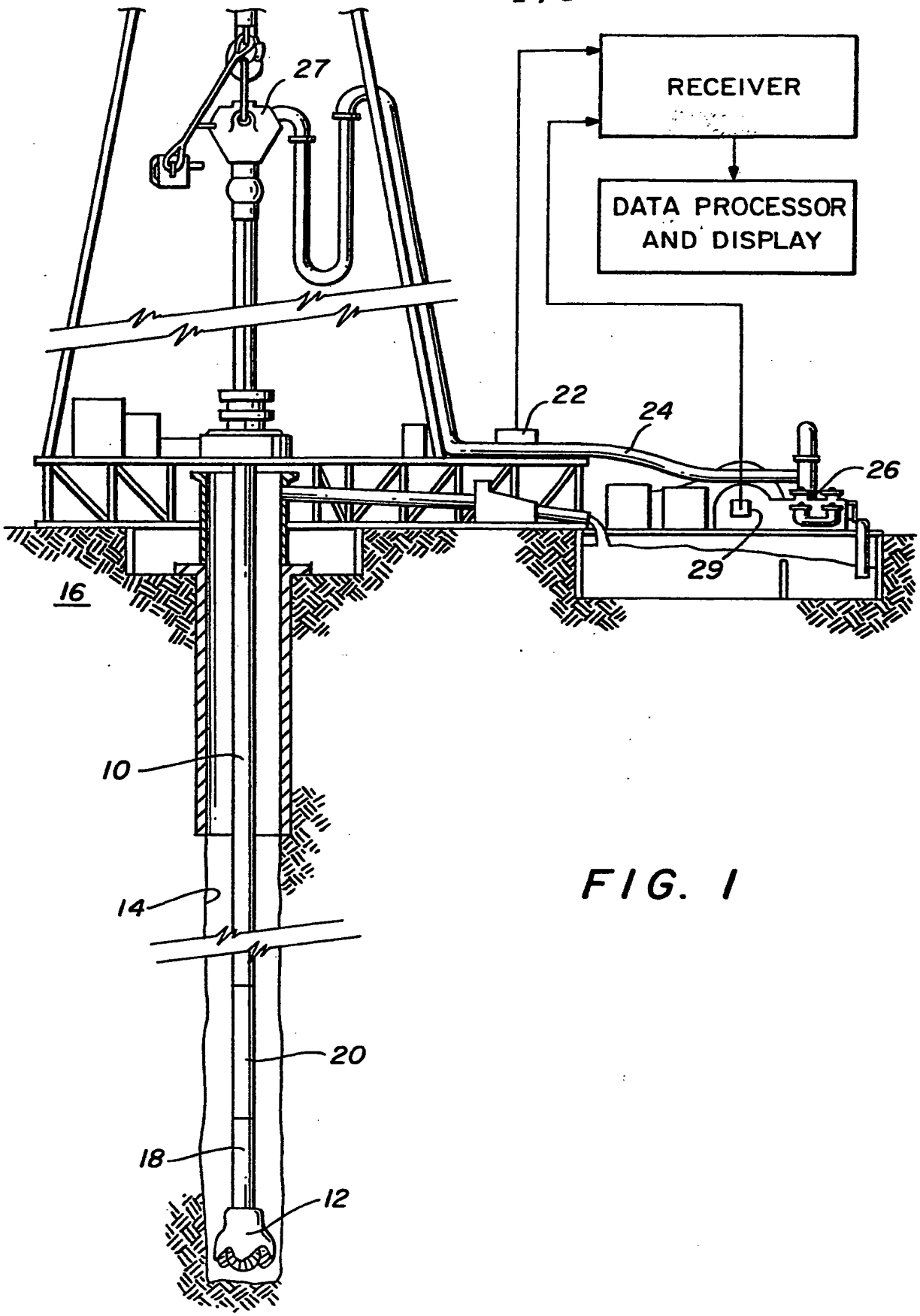

FIG. 1

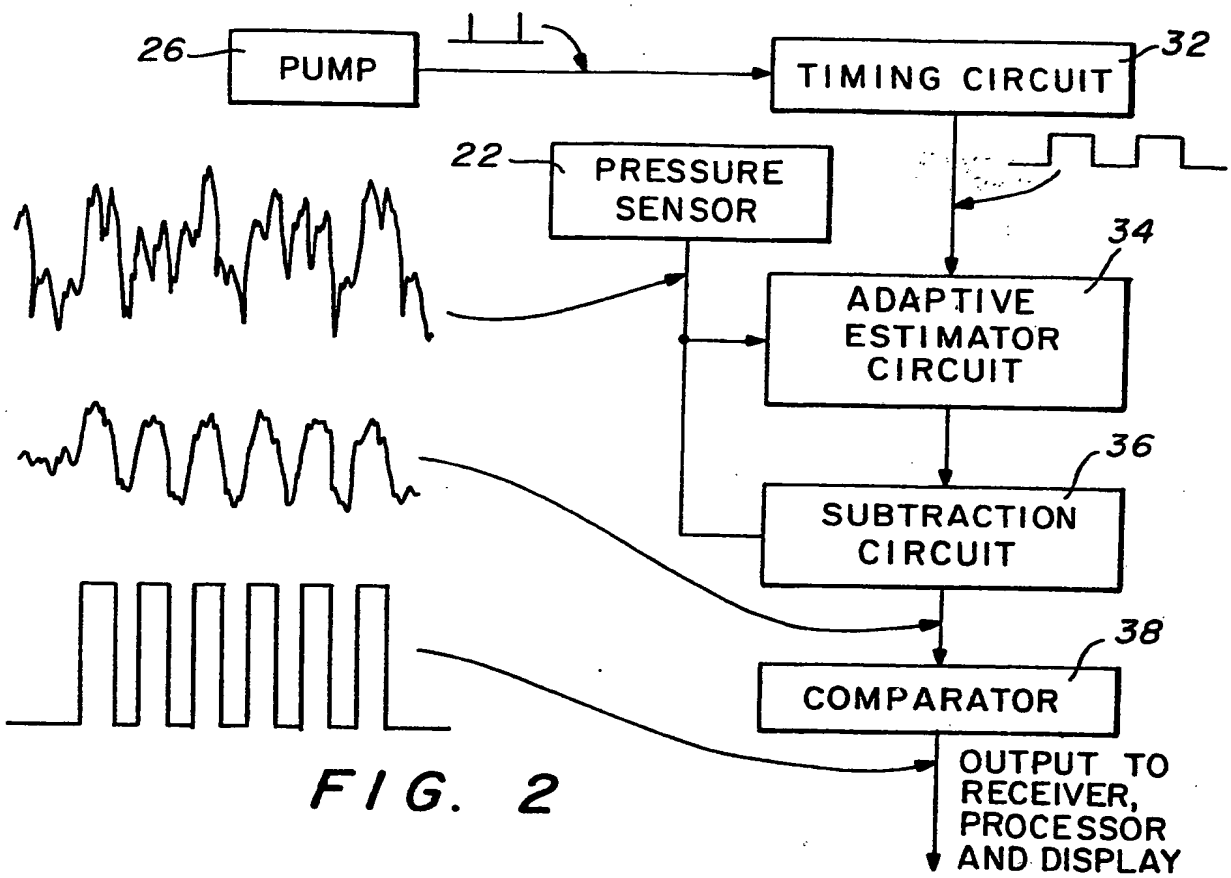

FIG. 2

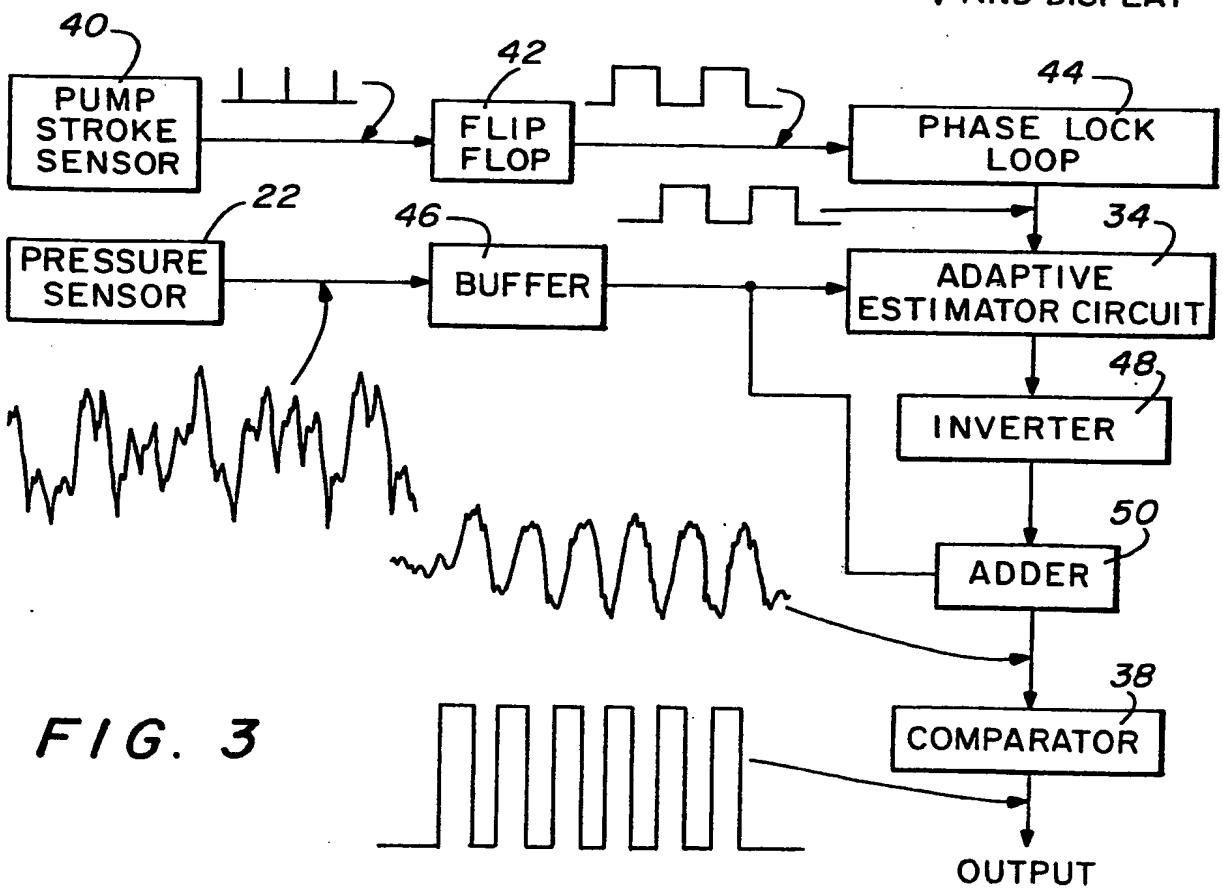

FIG. 3

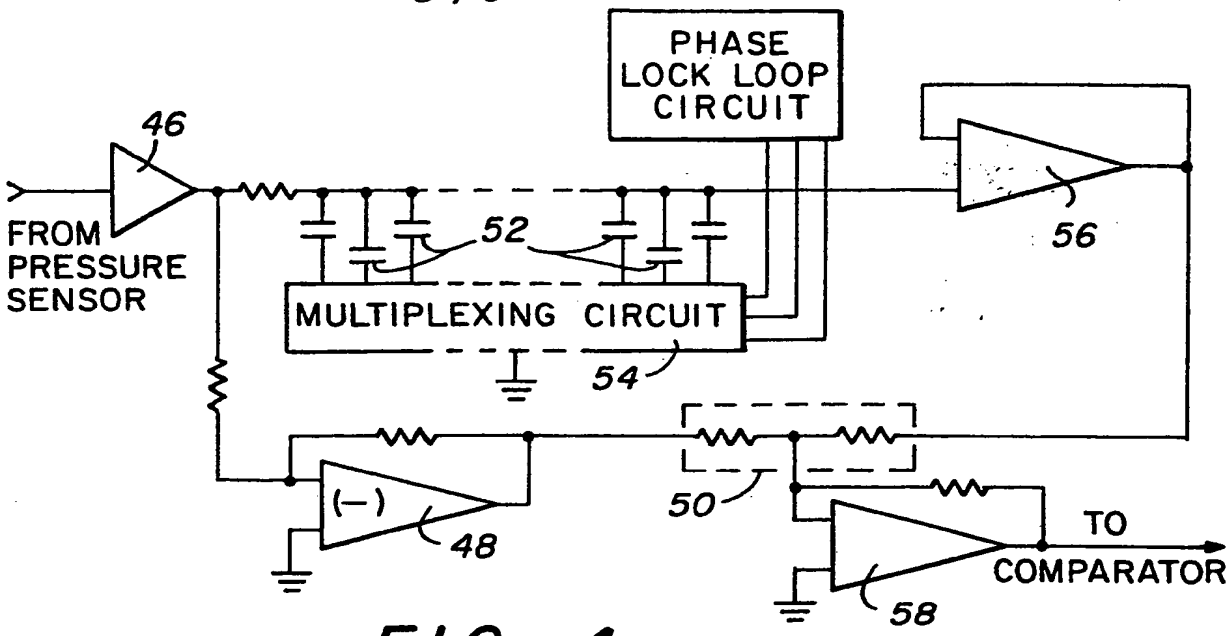

FIG. 4

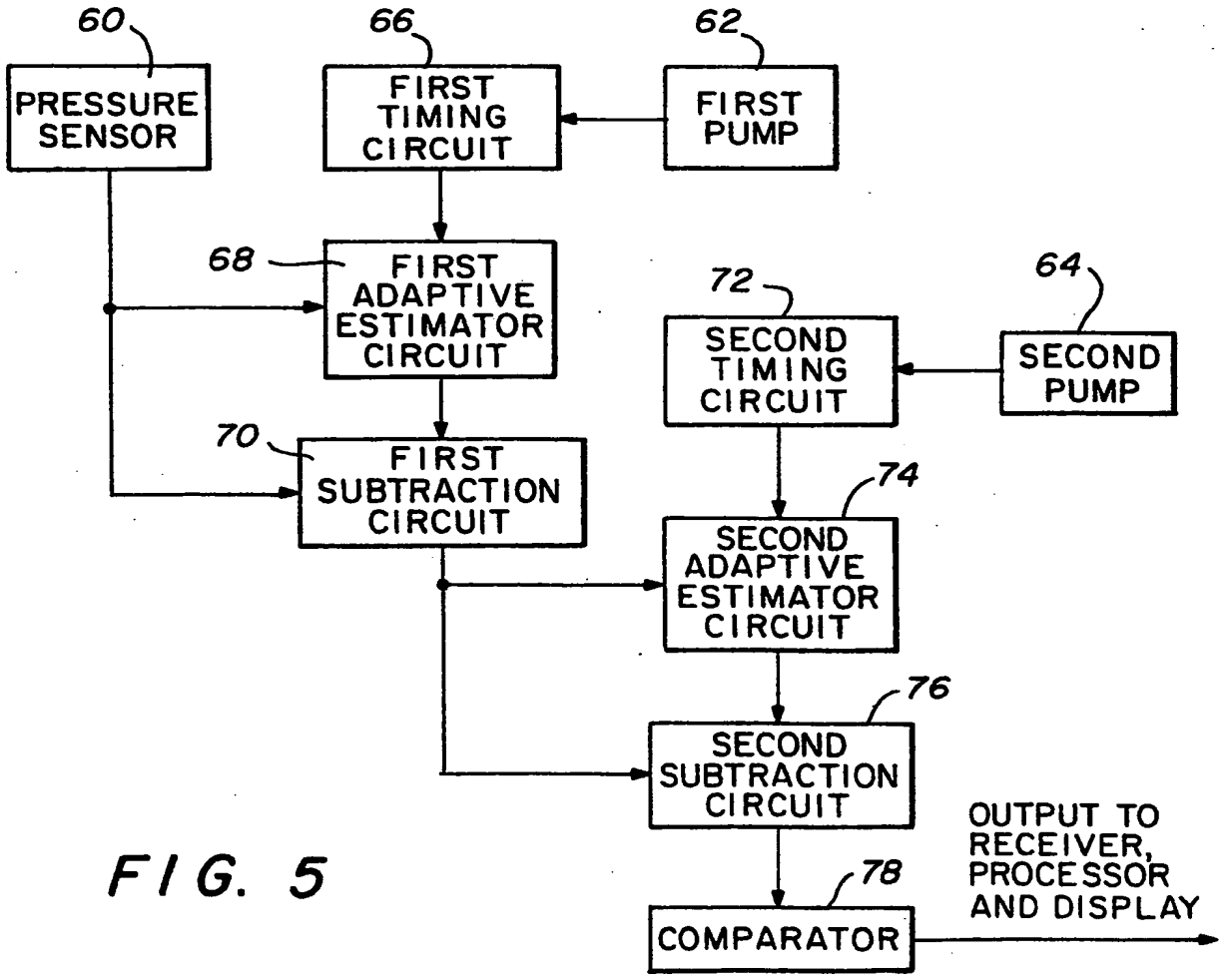

FIG. 5

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(54) Pump noise filtering apparatus for a borehole measurement while drilling system utilizing drilling fluid pressure sensing.

(57) An apparatus for removing pulsation noise caused by a well drilling fluid circulating pump from fluid pressure pulse transmitted measurement while drilling date passing through drilling fluid in a drill string of a borehole measurement while drilling system. The noise filtering apparatus includes a drilling fluid pressure sensor and an adaptive estimator that memorizes the pulse noise signature of a pump in synchronization with the pump's strokes. The memorized signature is removed from the signal data derived from pressure pulsations in the drilling fluid in order to remove or filter the pump's noise or pressure signal disturbing influence from this data. The adaptive estimator is arranged such that it will compensate for changing operating conditions of the pump so that this pump created noise is substantially, continuously filtered from the measurement while drilling date.

EP 0 078 907 A3

European Patent Office

EUROPEAN SEARCH REPORT

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. ³)
A	GB-A-2 009 473 (GEARHART-OWEN INDUSTRIES INC.) * Page 8, lines 29-49 *	1,11	E 21 B 47/12
A	US-A-4 093 923 (SHELL OIL CO.) * Column 1, line 55 - column 2, line 16 *	1,4,6	
A	US-A-3 714 623 (SCHLUMBERGER TECHNOLOGY CORP.) * Column 3, line 25 - column 4, line 56; figure 1 *	5	

TECHNICAL FIELDS SEARCHED (Int. Cl. ³)

E 21 B
G 01 V
G 01 H
H 04 L
H 04 B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	07-05-1984	ANDERSON A.TH.

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